Carbon Monoxide Levels in the Cabins of Small Un-pressurized Aircraft.

Jeff Smith, Class of 1989.

There are 9,110 general aviation aircraft in Alaska and 10,155 licensed pilots. Approximately one out of every 54 Alaskans is a licensed pilot and one out of every 60 residents owns an aircraft.[1] In Alaska, during the period 1963-1981, there were 3,887 aviation crashes involving 11,072 individuals. There were 513 fatal crashes resulting in a total of 1,366 fatalities, an average of 72 deaths per year and a fatality rate of 799 deaths per 100,000 pilots per year. In contrast, from 1980-1984 there were 599 traffic fatalities in Alaska, resulting in a fatality rate 39 per 100,000 drivers per year, or a rate 21 times less than found in aviation crashes (Figure 1).[2]

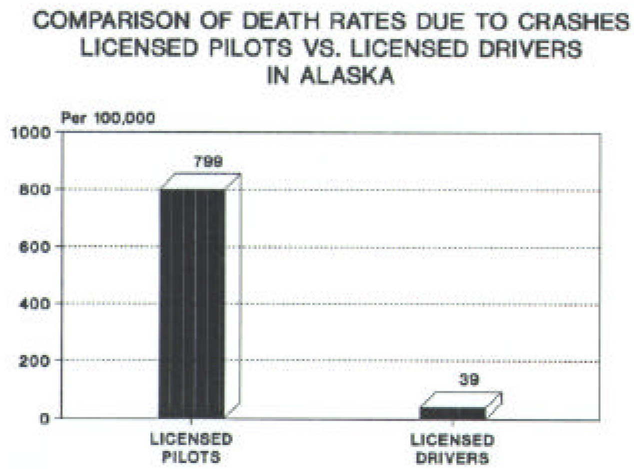


FIGURE 1: Middaugh (1986)

In Alaska, there were 23.54 crashes and 15.20 crashes per 100,000 hours flown in non-commercial aircraft and commercial aircraft respectively. In the U.S., excluding Alaska, the rates are 10.74/100,000 and 3.29/100,000 (Figure 2).[3]

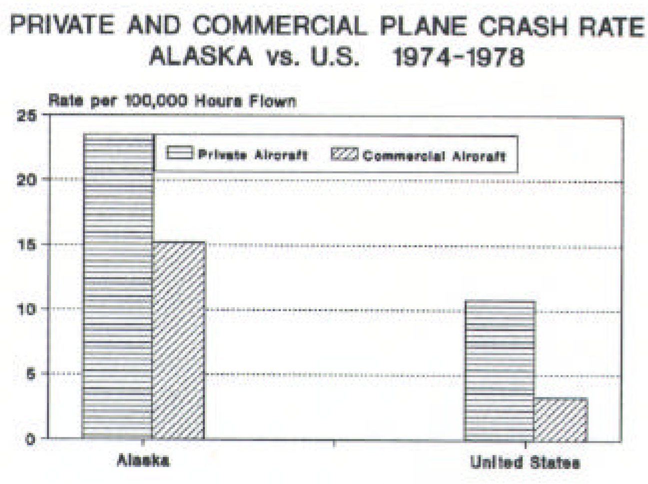


FIGURE 2: National Transportation Board (1980)

Carbon monoxide (CO) is a colorless and odorless gas. It is produced in high concentrations by internal combustion engines; approximately 3.5 percent (35,000 ppm) of motor exhaust is composed of CO.[4] Carbon monoxide enters the blood through inspired air where it binds to the hemoglobin of red blood cells and becomes carboxyhemoglobin (COHb). The chemical affinity of carbon monoxide for hemoglobin is approximately 210 times greater than oxygen. In addition, as the COHb increases, the oxygen which is in the blood is less available due to an increase of oxygen tensions. Overt symptoms of CO poisoning include headache, dimness of vision, weakness, nausea, confusion, slowed reactions, respiratory failure, lethargy, hallucinations, and death.

The Occupational Safety and Health Administration (OSHA) regulation for CO is 35 ppm, averaged over an eight hour day with a ceiling of 200 ppm. The National Institute for Occupational Safety and Health (NIOSH) guideline is 35 ppm with a 200 ppm ceiling. OSHA set the Immediately Dangerous to Life and Health Level (IDLH) at 1,500 PPM.[5] Studies have shown that these levels do not adversely affect the health of the average worker. However, other studies have shown that CO levels below these federal standards may produce impairments in both cognitive and psychomotor abilities which, while not directly affecting health, may deleteriously affect response time, accurate judgments and quick decision-making.[6] In addition, there is a synergistic relationship between altitude hypoxia and CO. As the amount or partial pressure of oxygen decreases as in an aircraft at altitude, the likelihood of a CO molecule binding with a heme group is increased.

Both uptake and excretion of CO are regulated by several factors, but chiefly by the number and volume of respirations of a given individual. “Half recovery time”, or that time needed for an individual to respire half the COHb, for resting adults breathing air at one atmosphere is 5.3 hours. The half recovery time can be escalated by increasing the amount of respirated oxygen and/or increasing atmospheric pressure.[9]

In 1983, the State of Alaska Epidemiology office, in conjunction with the National Transportation Safety Board (NTSB) and the Federal Aviation Administration (FAA), undertook a major study of aircraft crashes in Alaska during the period from 1963-1981.[10] This study found 13 crashes during the study period in which blood tests indicated CO poisoning as a probable cause. These results initiated a second study by the State Epidemiology Office of CO levels found in the blood of pilots and passengers in general aviation aircraft.[11] This study was conducted by drawing and analyzing blood from both passengers and pilots of small aircraft at one airfield in Anchorage, Alaska. This study found what was considered to be elevated COHb levels in pilots and passengers in seven aircraft out of the 54 involved. Blood was not drawn from individuals tested prior to the flight so it is unclear if the elevated blood levels were a result of exposure during the course of flying.

METHODS

Aircraft and pilots operating out of the State-of-Alaska-maintained airport facilities in Dillingham, Alaska participated in the study. Aircraft were defined as unpressurized, fixed-winged airplanes with a seating capacity of 12 people or less. Although initial attempts were made to select the participating aircraft, aircraft owners, and pilots at random, most pilots or aircraft owners were ultimately volunteers solicited for the study.

The Interscan Model 7000, with a detection range of 0-500 ppm, was chosen as the instrument for CO surveillance. A highly sensitive instrument with an integral sampling pump, the Model 7000 is able to record and store data over time. The Interscan monitor/sampler collects and stores a sample each second while in operation, then averages the 60 one-second samples into a one-minute average reading. The monitor records and stores the peak sample concentration, including the time the peak reading occurred in a given sampling period.

In most cases, the monitor was located between the pilot's and copilot's seat during the flight. On a few occasions, due to space constraints, it was located on the floor in front of the co-pilot or in the seat behind the pilot. A flexible sampling tube was attached to the intake port of the instrument and the opposite end of the sampling tube was clipped to the collar of the pilot's coat within six to twelve inches of the pilot’s breathing zone.

In an attempt to determine if varying CO levels corresponded to various maneuvers of the aircraft, such as taking off or climbing, the author accompanied the pilot on each of the flights. During the flight, the investigator recorded the times of a variety of maneuvers for later comparison with the recorded CO levels from that time frame.

The CO instrument was calibrated at least once per day prior to flights, usually with both a standardized 60 ppm and a 300 ppm CO gas mixture and calibrated again prior to the next flight. Because some of the samples took place in extremely cold weather (-30^{o} F), the instrument was maintained at room temperature until immediately preceding the flight. Following each flight, the monitor was returned to the Environmental Health and Safety Office at Kanakanak Hospital where the recorded data was downloaded to an IBM compatible computer via the RS-232 port. The downloading procedure was controlled by the Interscan CX-5 Interface System software. This software was also used for some of the initial data manipulation.

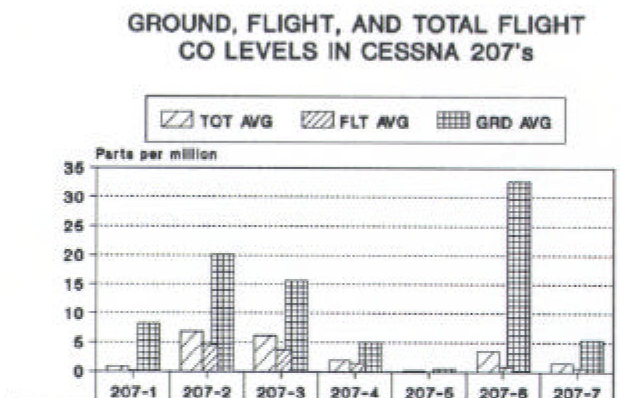
In addition to the CO data collected, the pilot or aircraft owner was asked a brief series of questions regarding the airplane. The information solicited consisted of data regarding the type, make, year of manufacture, etc., of the aircraft. The detailed questionnaire can be found in the appendix of this paper. The data collected from the questionnaire was entered into the software program EPI Info (Version 5) and analyzed with the regression analysis function.

A total of 17 aircraft, eight private and nine commercial, were monitored during the study. This represents approximately 50 percent of the commercial aircraft and 14 percent of the private aircraft located at the Dillingham airport and meeting the study definition. The average length of the flights was 96 minutes and the average temperature for all flights was 26 degrees Fahrenheit.

At some point during the course of each flight, 15 of the 17 (88 percent) aircraft tested showed levels of CO above the ambient level and 76 percent had levels considerably higher than background. Seven of the 17 aircraft attained readings higher than the OSHA and NIOSH standard of 35 ppm. However, in most cases, the high levels occurred for only brief periods of time. In 14 of the 17 aircraft monitored, the peak CO level occurred while the plane was on the ground either warming up or taxiing. In 76 percent of the aircraft, the average of the CO levels recorded while on the ground was higher than the average level during flight (Figures 3). The averaged "ground" CO levels for all flights was higher than the averaged levels while in flight (12.17 ppm vs. 6.15 ppm). When both the ground and flight levels were averaged for the entire flight sequence (ground and air time), the resulting average for all of the flights was 7.55 ppm.

The CO concentrations measured in privately owned aircraft were considerably higher then in the commercial aircraft monitored. The average level recorded on the ground for both the private and commercial aircraft was similar. However, the average CO level measured during flight and for the total flight (ground average plus flight average) was much lower in the commercial aircraft.

For unexplained reasons, three of the Cessna manufactured aircraft tested, the Cessna 207#5, the Cessna 180 and Cessna 185, had very low levels of CO both on the ground and in flight (Figure 3). The twin engine aircraft tested, a Piper Navajo, also had low levels which were likely the result of the engine's location on the wings of the aircraft where the exhaust was not likely to blow into the cabin. The three PA-18 Piper Cubs had high readings throughout the course of the flight. These were the only planes tested which produced higher concentrations of CO while in the air then while on the ground.



	207-1	207-2	207-3	207-4	207-5	207-6	207-7
TOT AVG	0.85	6.86	6.17	1.91	0.2	3.53	1.56
FLT AVG	0.165	4.65	3.75	1.5	0	0.85	0.66
GRD AVG	8.3	20.1	15.6	5	0.5	32.7	5.5

FIGURE 3

The levels recorded during 10 of the flights followed a very similar pattern. After the engine was started, the CO levels climbed to a plateau while the plane warmed up and taxied. Once the aircraft left the ground, the CO readings dropped back to ambient or near ambient levels. When the plane landed, the levels again climbed back up until the engine was shut down and the doors opened.

Additional data on each aircraft was evaluated using regression analysis. This additional information, such as wind speed, temperature, year of manufacture of the aircraft, total hours of flight time on the aircraft, and length of time since the last inspection, showed little if any correlation with the CO concentrations measured.

Flying maneuvers of the different aircraft did not appear to increase or decrease the level of CO in the cabin. Levels recorded during take off, climbing, descent, landing, and turns were no different than the CO concentrations recorded during level flight. Level flight at different altitudes in the same aircraft produced no discernible difference in the amount of CO present in the aircraft.

DISCUSSION

In 14 of seventeen aircraft, the peak CO concentration was recorded while the plane was on the ground. While the average CO levels found for an entire flight were, for the most part, well below the OSHA and NIOSH work place standards, the levels found may still be of concern to pilots and aircraft owners. Pilot skills requiring a high level of alertness and, at times, split-second decision making capabilities are impaired by exposures to sufficient quantities of CO. In addition, altitude hypoxia and CO have a synergistic relationship resulting in pilots being particularly vulnerable to the effects of CO poisoning. As a result, pilot performance may be impaired by exposures to CO concentrations below the OSHA and NIOSH standards.

The main ports of entry for carbon monoxide into the aircraft were not identified. Three of the Cessna manufactured aircraft showed virtually no CO at any time during take off, flight or landing. In three other aircraft, the Piper PA-18 Cubs, the highest concentrations of CO were recorded while the aircraft were in flight. The pilot of one of these aircraft (Cub #1) acknowledged having a loose fitting in the plane's exhaust system which may have accounted for the high CO levels in that plane. The other two Cubs, although the recorded levels of CO were lower, also had elevated CO levels during flight. It appears there is a design characteristic of these airplanes which allows engine exh aust to enter the cabin of the aircraft during flight.

The average outside temperature during the monitored flights was 26 degrees Fahrenheit. These relatively cold temperatures necessitated full heat into the cabin on all but one of the 17 flights. Because the heat is provided by air circulated through the aircraft's exhaust manifold, the heating system is one likely source of CO into the cabin. Future measurements at warmer temperatures will be necessary to confirm this possible source of CO.

RECOMMENDATIONS

1. All small fixed-wing aircraft should be equipped with a CO detection device. Either the passive dosimeter type which are relatively inexpensive or a specialized aviation electronic detector should be installed. This is particularly true for owners of Piper PA-18's.

2. Pilots should, whenever possible, avoid sitting in the aircraft for prolonged periods while the plane is on the ground with the engine running.

3. Immediately after take off, the pilot should ventilate the aircraft as much as possible by opening the air intake vents or a window if available. After landing, the doors should be opened as soon as feasible.

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